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Research and Development Report

Instrumented Impact Testing of Composite Materials

by

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DTRC-SME-88/73 Instrumented Impact Testing of Composite Materials

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One material characteristic that is gaining increased importance in composite material is their impact resistance. The test method that has been widely accepted in the aerospace industry for determining a degree of "toughness" is the instrumented impact test followed by post-impact compression testing. This combination of tests is called compression after impact (CAI) testing. Two aspects that are important to the results are the energy absorbed during the impact test and the resultant compression strength after impact. This paper discusses the instrumentation developed to record the impact event. The hardware and software are presented with a detailed description of the algorithms used for the determination of the energy absorbed by the composite from the impact testing. Sample results from the impact testing are presented, along with a discussion of their results.

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ABBREVIATIONS

CAI - compression after impact
Corp. - Corporation
ft. - foot
ft-lb - foot pound
in. - inch
in-lb - inch pound
ksi - thousand pounds per square inch
lb. - pound force
sec. - second

ABSTRACT

One material characteristic that is gaining increased importance in composite materials is their impact resistance. The test method that has been widely accepted in the areospace industry for determining a degree of "toughness" is the instrumented impact test followed by post-impact compression testing. This combination of tests is called compression after impact (CAI) testing. Two aspects that are important to the results are the energy absorbed during the impact test and the resultant compression strength after impact. This paper discusses the instrumentation developed to record the impact event. The hardware and software are presented with a detailed description of the algorithms used for the determination of the energy absorbed by the composite from the impact testing. Sample results from the impact testing are presented along with a discussion of their results.

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INTRODUCTION

Advanced composite materials are gaining increased use in structural applications within the Navy. Although their use in aircraft has been met with great enthusiasm, their use on Naval vessels has less impact since weight reduction transitions into only a minimal dollar savings. Recently, however, there have been numerous applications identified which can utilize other material characteristics of composites that have the potential to provide the Navy with structures with improved performance.

In their service environment, these composite structures will inevitably be subjected to impact damage from numerous sources such as dropped tools, debris in the water and from moving equipment. Thus, the materials used must be capable of sustaining an impact and having residual properties which will still meet the structural requirements. Knowledge of the impact performance of the various material systems is necessary to ensure their appropriate selection for the specific applications. In addition, impact response testing of test coupons will provide the designer with information to approximate the extent of damage that may result in the service environment for the structure. This will allow development of repair procedures for anticipated damage.

One method of assessing the damage tolerance or toughness of composite materials is through instrumented impact followed by determination of the residual ultimate compression strength. A test method currently used by the aerospace community utilizes a composite panel with dimensions 4 x 6 in., and a thickness of approximately 0.25 in, which is clamped to a rigid base and supported on all edges. This specimen is then subjected to an impact from an instrumented force head. The output from the force head is measured, recorded displayed as a force vs. time curve. From this information, the energy absorbed by the composite panel can be determined. This energy can be identified either as the energy lost, which caused damage; or the energy stored, which is returned to the drop weight as kinetic energy. From this information and results from the residual compression strength testing, a qualitative understanding of how the material will respond in service can be deduced.

This test method is currently an accepted industry practice to rank the damage tolerance or toughness of various composite materials. Typically, the composite is impacted with an energy of 1500 in-lb per inch thickness of material.(1) After impact, the material is subjected to a compression test using a fixture which supports the specimen on all sides. The failure strength is recorded and materials ranked according to their compression after impact strength. The goal of the aerospace industry is for the material to have a compression after impact strength of approximately 50 ksi.(1)

The rationale for performing a compression test on a sample after it has been impacted is the following. Damage in a composite from impact can manifest itself as matrix cracking, delamination, fiber/matrix debonding, and fiber breakage.(2,3) All of these forms of damage will cause a reduction in the compression strength of a composite, especially the delamination. In tension or shear loading, however, a reduction in strength from the above forms of damage will be minimal. Compression testing on impacted materials is, therefore, the most severe testing that can be performed and provides a means for damage tolerance screening.

EXPERIMENTAL PROCEDURE

The impact testing was performed using a Dynatup drop tower, from the General Research Corp. The tower is capable of a maximum drop height of 10 ft. The weight of the impactor can be varied from 15.1 lb to 39.1 lb, however, the maximum available impact energy for this system is 90 ft-lb.

Two rods direct the force tup attached to the impact head to a center hole in the base of the upper support structure. For the instrumented impact of specimens on which compression after impact testing will be performed, a fixture is attached to the base of the drop tower, directly under the upper support plate. This fixture consists of a 0.5 in. steel plate with a 3.0 x 5.0 in. rectangular hole in its center which is aligned with the center of the hole in the upper support plate. The center of the fixture hole is therefore aligned to correspond to the center of the instrumented impact head. Four spring loaded clamping devices are attached to the fixture, in close proximity to the cut out, two along each of the 5 in. sides. There are also 4 alignment pins positioned on two adjacent sides, approximately 0.5 in. from the cut out. The fixturing is such that a 4.0 x 6.0 in. specimen can be clamped, centered around the cut out, and supported by 0.5 in. along all sides.

To conduct an instrumented drop tower test, a 4.0 x 6.0 in specimen is clamped onto the test fixture. The drop head is raised so that the tip of the instrumented force tup is a specified height above the test specimen. A specified weight is loaded into the drop head. The force tup is electronically connected to a Vishay 2310 signal conditioner amplifier, which has been statically calibrated. The output of the signal conditioner amplifier is connected to a Metrabyte Dash16 analog to digital computer board, installed in an IBM PC AT, where the output of the force tup is recorded. An analog trigger is utilized to initiate the collection of the data by the Dash16 board. This consists of a General Electric 8743 H21L1 optoelectronic sensor which is supplied with a 5 volt DC signal. The trigger is attached to a support beam attached to the upper support plate of the drop tower. The trigger can be positioned at various heights along this beam owing to a slotted region into which the trigger is attached. The output of the trigger is connected to a channel of the Dash16 data acquisition board. To activate the trigger, a 0.0625 in. thick by 0.375 in wide steel plate is attached to the drop head. As the drop head is allowed to drop, when the tip of the force tup is approximately 0.5 in. above the test specimen, the steel plate passes through the trigger. When this occurs, the trigger sends out a 5.0 volt signal to the data acquisition board. This rising voltage signal sends the computer program from a wait loop into the data acquisition routine.

DATA ACQUISITION SYSTEM

The data acquisition system consists of a 16 channel Dash16 analog to digital computer board from Metrabyte Corp. which is installed in an IBM PC AT computer. The computer software written to record and convert the voltage output from the force tup is included as Appendix 1. The initial data acquisition and data manipulation consists of various call routines supplied with the Dash 16 board. These routines set up the channel to read the force tup, the channel to be used for the trigger and the rate of data acquisition. The voltage output from the force head is read and stored using direct memory access. Once the specified number of data points are read into memory, the information is read into an array. The information is then converted into a force using appropriate scaling factors previously determined for the specific force tup, and stored into a file specified by the user.

The force vs. time information is then used to determine the acceleration, energy, velocity and distance vs. time information. The algorithms used are as follows.

The force that is read by the force tup is the total force on the composite panel (the mass times the acceleration of the force head). The acceleration of the force head is the acceleration of gravity, g, minus the acceleration that the composite panel exerts on the head itself. The force that the composite experiences is given as

$$\text{FORCE ON THE COMPOSITE} = mg - ma \tag{1}$$

where the force on the composite is that force read from the force tup and mg is the force due to gravity of the force head.

In equation 1, the only unknown is the acceleration of the tup, a. Rearranging equation 1, the acceleration can be solved for as

$$a = g - \frac{\text{force}}{m} \tag{2}$$

or using the weight of the drop head, IW, equation 2 becomes

$$a = \left(1 - \frac{\text{force}}{IW}\right) \times g \tag{3}$$

Using equation 3, the acceleration of the drop head is determined each time the tup force is read. In this case, the force is read every 0.00013 sec.

The initial velocity of the drop head as it strikes the composite panel can be calculated. The maximum potential energy, PE, of the system is determined from the drop height of the tip of the force tup above the panel. This is given as

$$PE = mgh \tag{4}$$

where m is the mass of the drop head, g is the acceleration due to gravity and h is the height of the tip of the force tup above the panel.

As the tup hits the panel, the maximum potential energy is converted into the maximum kinetic energy, KE, assuming that there are no other losses such as friction or buoyant resistant forces. The kinetic energy is given as

$$KE = \frac{1}{2} m v^2 \tag{5}$$

where v is the velocity of the force tup at impact. The initial velocity of the force head can then be determined by equating equations 4 and 5 and solving for v. The initial velocity, v_{init}, is given as

$$v_{init} = \sqrt{2\ g\ h} \tag{6}$$

The velocity at a particular time corresponding to the force output is determined from the previous velocity and the average acceleration. To compute the velocity at a particular time, t_i, the acceleration at time t_i and t_{i-1} and the velocity at time t_{i-1} are required. The velocity, then, is given by

$$v_i = v_{i-1} + \left(\frac{a_i + a_{i-1}}{2}\right) \times \Delta t \tag{7}$$

where Δt is the time interval between data points and $\left(\frac{a_i + a_{i-1}}{2}\right)$ is the average acceleration in the time interval t_i and t_{i-1}.

The increment in displacement at each time interval can then be determined from the velocities. The displacement is computed by taking the average velocity multiplied by the increment in time added to the previous displacement and is given as

$$x_i = x_{i-1} + \left(\frac{v_i + v_{i-1}}{2}\right) \times \Delta t \tag{8}$$

The energy absorbed can then be determined from the velocities and displacements. These are used to compute the kinetic and potential energy imparted to the panel. The energy absorbed by the panel, E_a, is given as

$$E_{a_i} = E_{a_{i-1}} + \frac{1}{2} m \left(\frac{v_i + v_{i-1}}{2}\right)^2 - m g \Delta x \tag{9}$$

where $m g \Delta x$ is the reduction in the potential energy below the reference level, i.e. the top of the composite panel.

The computer routine that performs these calculations is given in appendix 2.

Once the force, acceleration, velocity, distance, and absorbed energy are determined and stored to a file, the information is imported into Lotus 123. In Lotus 123, the information is graphed and stored to a file for subsequent printing using the PGRAPH program in Lotus 123.

Although the energy absorbed is the information that is desired from this testing, through the analytical determination of the velocity and displacement, and comparison to the physical characteristics of the test (e.g input energy and panel indentation), the validity of the calculated energy can be assessed. The reason for this is that the velocity is determined from the acceleration and the distance determined from the velocity. Any inconsistancies in the velocity and distance information will effect the results for the absorbed energy.

EXPERIMENTAL RESULTS

To provide a sample output of the data analysis routine, a graphite/epoxy, AS-4/3501-6, panel was fabricated. This panel was 16 ply quasi-isotropic with orientations $[45/0/-45/90]_{2S}$. The panels were vacuum bagged and autoclave cured using the manufacturers recommended cure procedure. After processing, the panel was nondestructively inspected using ultrasonic C-scan to assure part quality and machined into specimens with dimensions 4 x 6 in.

The specimens were then impacted with varying energy levels, one each at 500, 750, 1000, 1500, and 2000 in-lb per inch thickness. Table 1 indicates the specific drop heights, weights and maximum impact energies.

The recorded force time information is graphically presented in figures 1-5. The interesting point to note is that there is a common force level at which all of the curves become nonlinear. This nonlinearily is not a function of the test equipment or electronics, as was demonstrated through additional testing, but is an actual material characteristic. This would tend to suggest that there is an energy dissipation mechanism occurring at this force level which is controlled by the fiber characteristics.

The calculated velocity vs. time information is graphically presented in figure 6. The results presented are qualitatively correct as seen by the terminal velocity of the tup as it leaves the panel being less than the intial velocity of the tup as it struck the panel.

The calculated displacement vs. time information is graphically presented in figure 7. It is seen that at the low energy level, the panel shows no permanent deformation, i.e. the displacement returns to zero. At the higher levels, there is a permanent displacement predicted by the analysis. This permanent deformation is an actual artifact of each of these panels, i.e. an actual indentation remains in the panel after test. Measurement of the identation revealed an aggreement to the analytically predicted indentation to within 5%.

Finally, the energy vs. time information was analytically determined and is presented graphically in figure 8 for all samples. The results show that at the lowest impact energy level, the composite is able to elastically absorb the majority of the energy imparted to it. At increasing impact energy levels, damage is seen to occur, i.e. the energy absorbed elastically by the material is less than the energy imparted to the material. The energy absorbed elastically by the material is the difference of the maximum of the energy vs. time curve minus the energy at the end of the test.

CONCLUSIONS

The computer data acquisition system that was designed and installed can accurately read and record the force level from the instrumented force tup. The analysis program, using algorithms to determine the acceleration, velocity, displacement and energy as a function of time, was shown to be qualitatively correct.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Mr. Lee Gauss of the Naval Air Development Center for providing information regarding the analysis routines used for his impact testing of composite materials. The authors would also like to thank Dr. Vincent Castelli for his helpful suggestions for optimizing the data acquisition and analysis computer routines and for fabricating the electronic trigger to initiate the data acquisition program. All of these facets have aided to provide an efficient and accurate data acquisition system for impact testing. Finally, the authors would like to express their thanks to Mr. Thomas Mixon for his expedient preparation and inspection of the composite materials used in this investigation.

Table 1. Drop height used and approximate calculated impact energy level imparted to the 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS4/3501-6 graphite/epoxy specimens.

Specimen No.	Thickness (in)	Drop Height (in.)	Calculated Impact Energy Level (in-lb/in thickness)
A	0.085	2.80	500
B	0.085	4.20	750
C	0.085	5.60	1000
D	0.085	8.40	1500
E	0.085	11.20	2000

Note: Force tup was a 0.5 in. diameter tup with a drop head weight of 15.1 lb

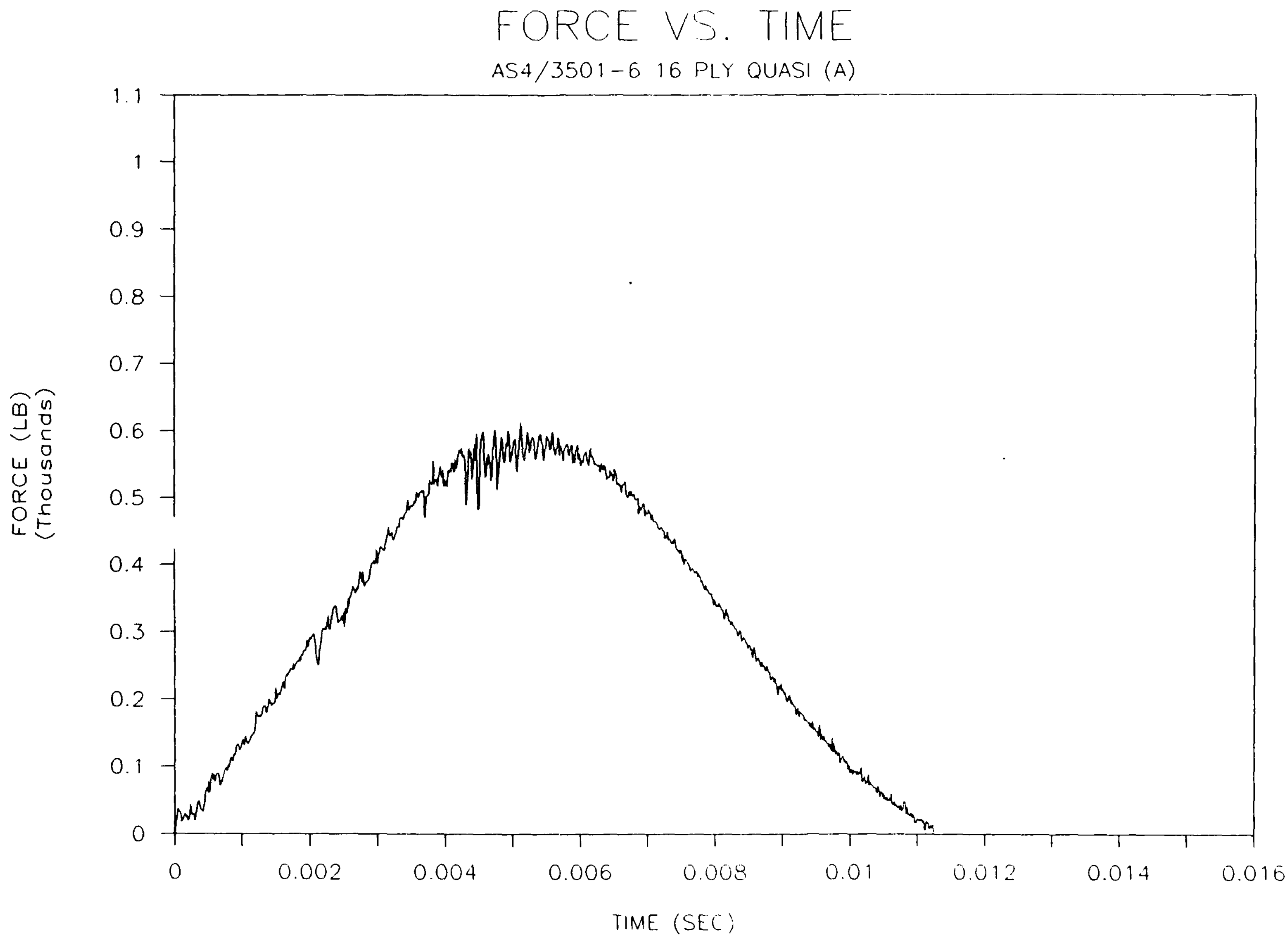

Figure 1: Measured force vs. time response of a 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS-4/3501-6 graphite/epoxy panel impacted with a 0.5 in. diameter tup at an energy level of 500 in-lb/in. thickness, specimen A.

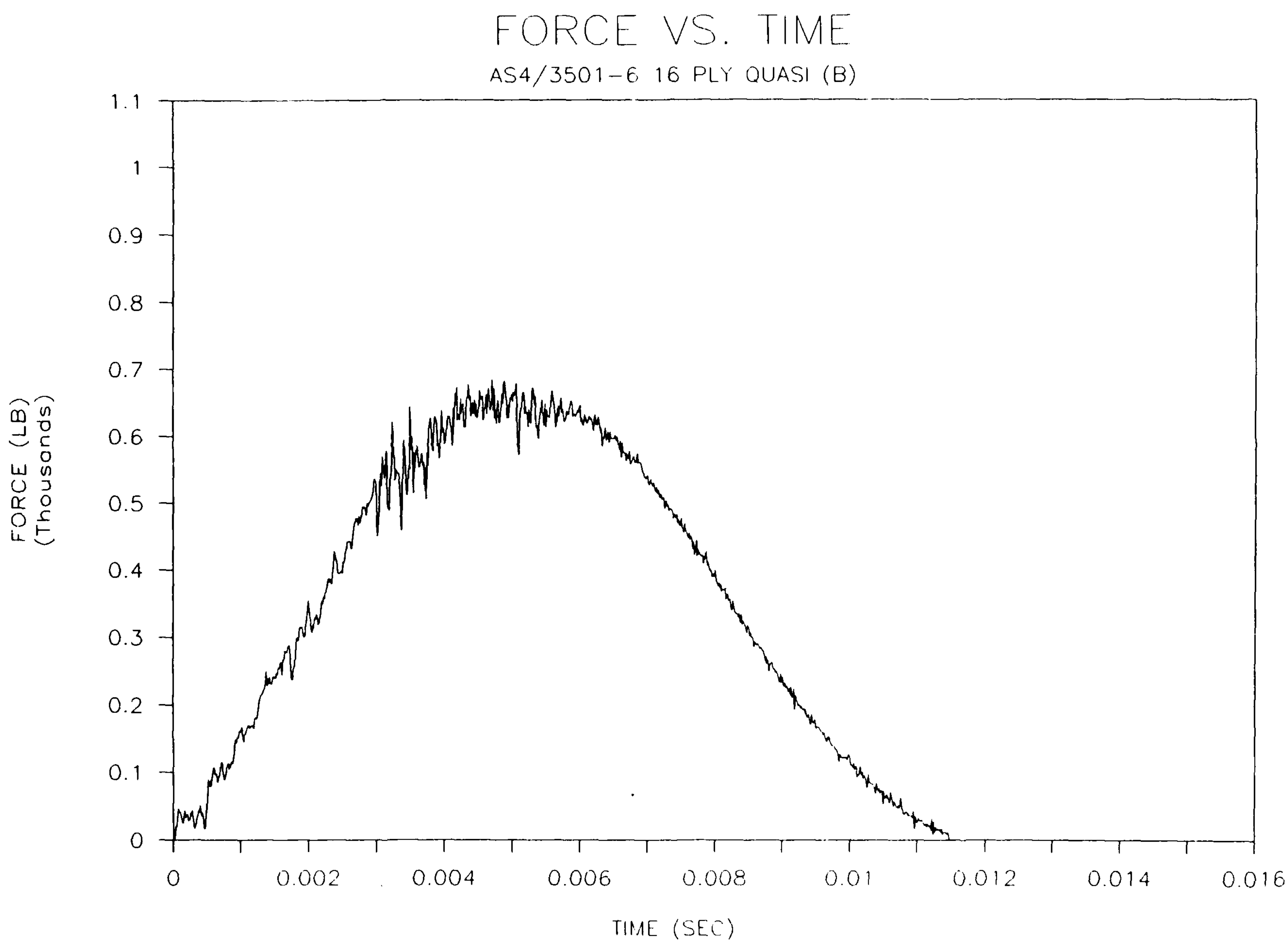

Figure 2: Measured force vs. time response of a 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS-4/3501-6 graphite/epoxy panel impacted with a 0.5 in. diameter tup at an energy level of

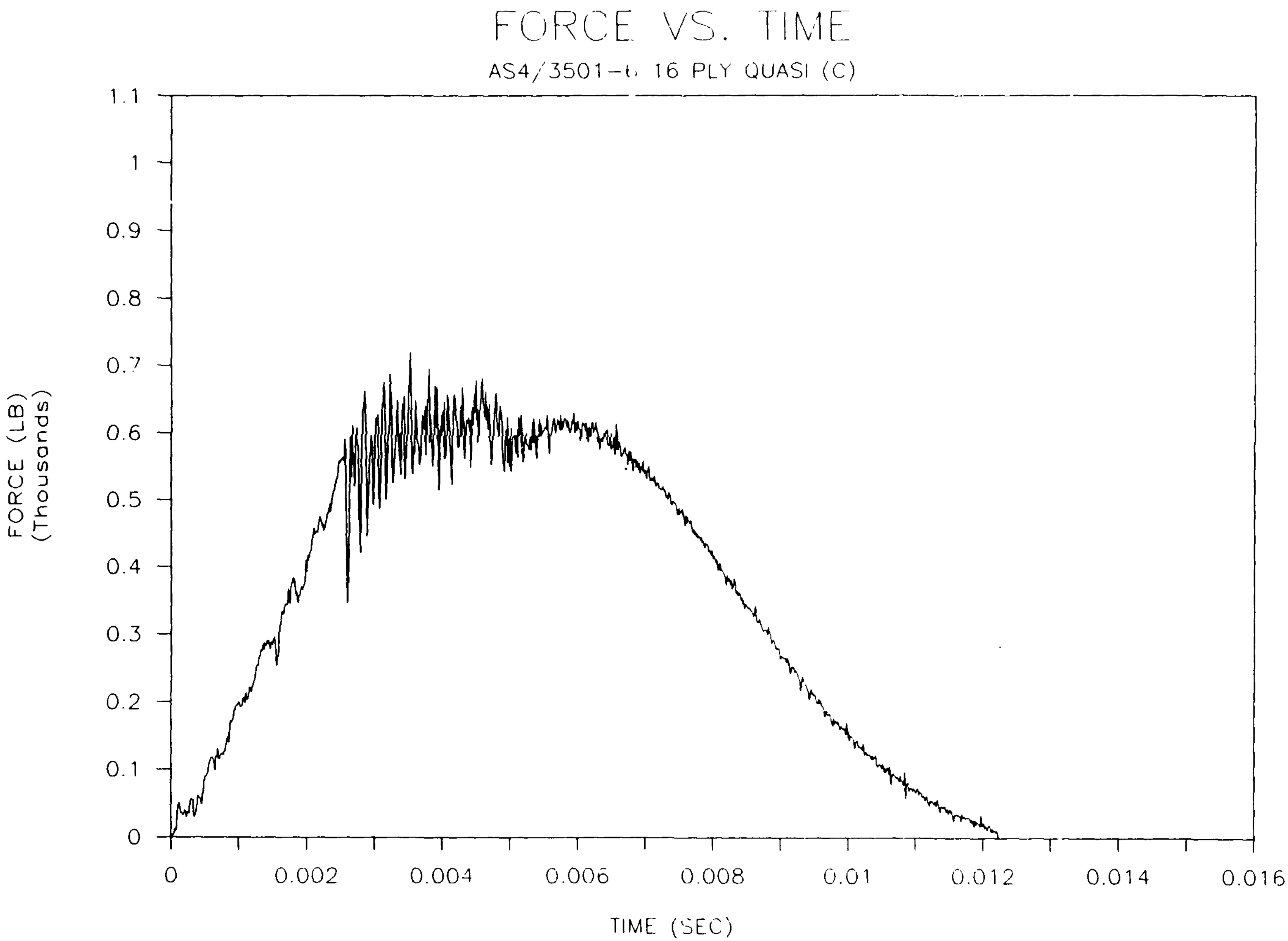

Figure 3: Measured force vs. time response of a 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS-4/3501-6 graphite/epoxy panel impacted with a 0.5 in. diameter tup at an energy level of 1000 in-lb/in. thickness, specimen C

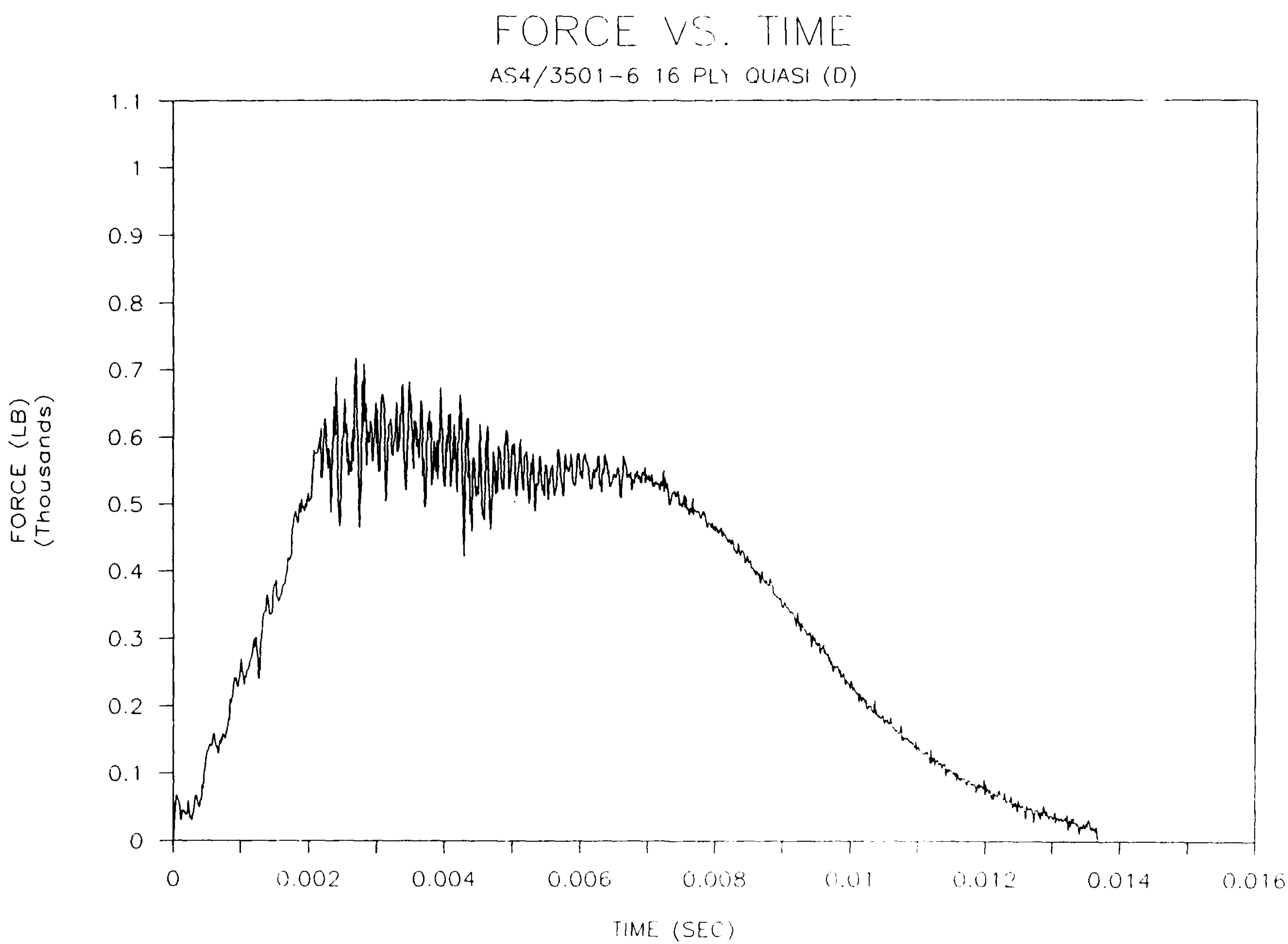

Figure 4: Measured force vs. time response of a 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS-4/3501-6 graphite/epoxy panel impacted with a 0.5 in. diameter tup at an energy level of 1500 in-lb/in. thickness, specimen D.

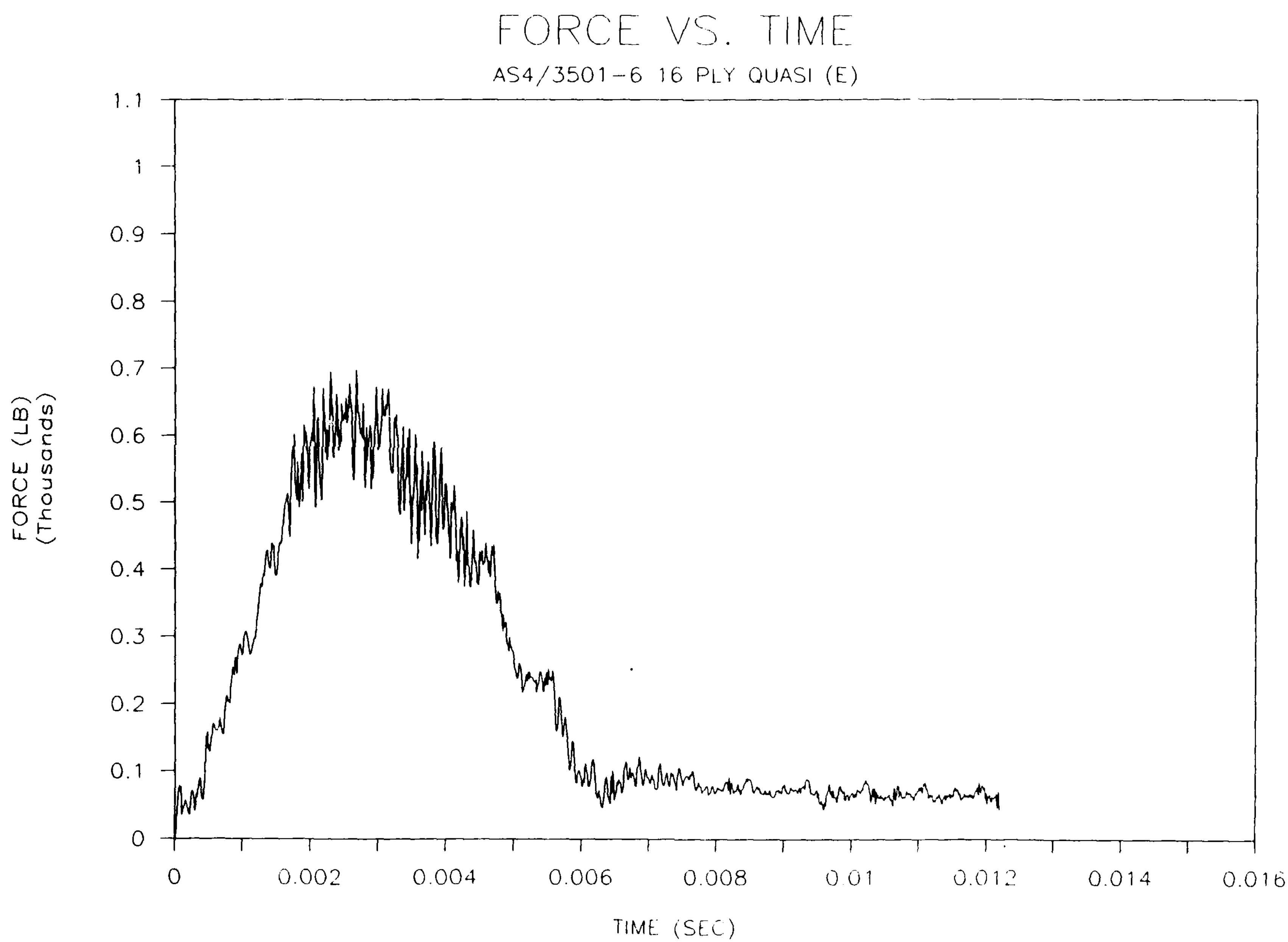

Figure 5: Measured force vs. time response of a 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS-4/3501-6 graphite/epoxy panel impacted with a 0.5 in. diameter tup at an energy level of 2000 in-lb/in. thickness, specimen E.

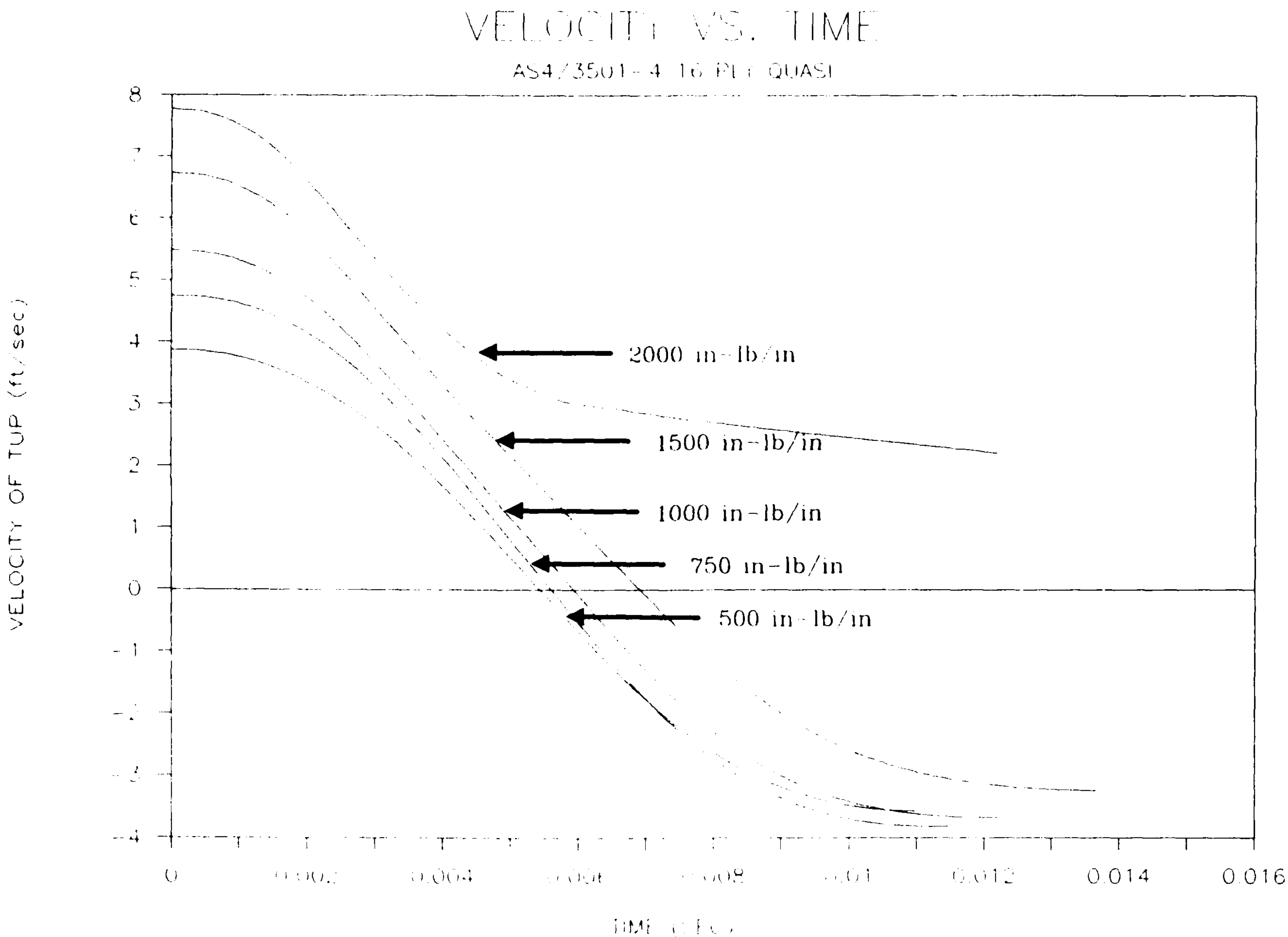

Figure 6: Calculated velocity vs time response of 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS4/3501-6 graphite/epoxy, specimens A-E, impacted with a 0.5 in. diameter tup, determined using equation 7

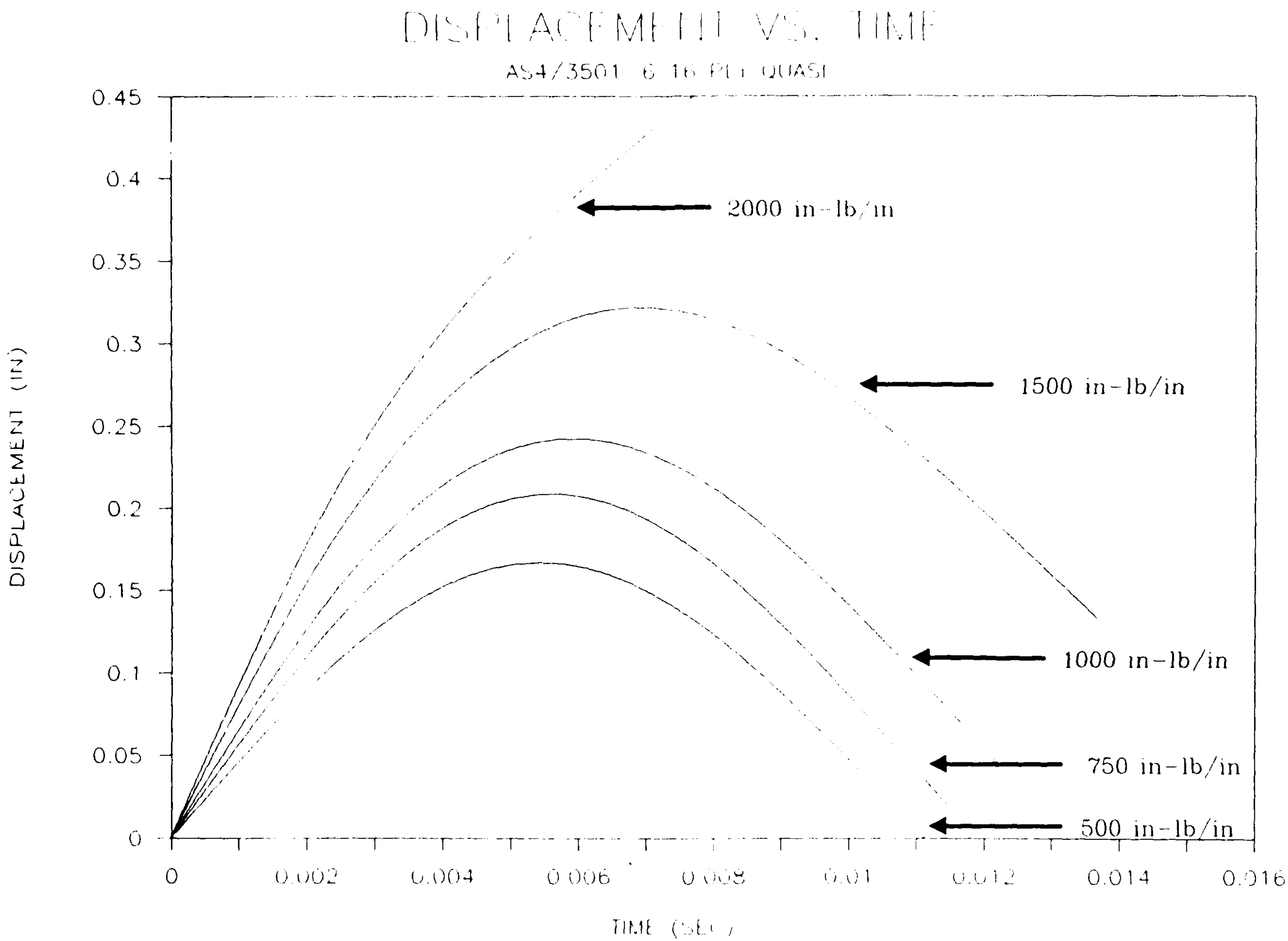

Figure 7: Calculated displacement vs. time response of 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS4/3501-6 graphite/epoxy, specimens A–E, impacted with a 0.5 in. diameter tup, determined using equation 8.

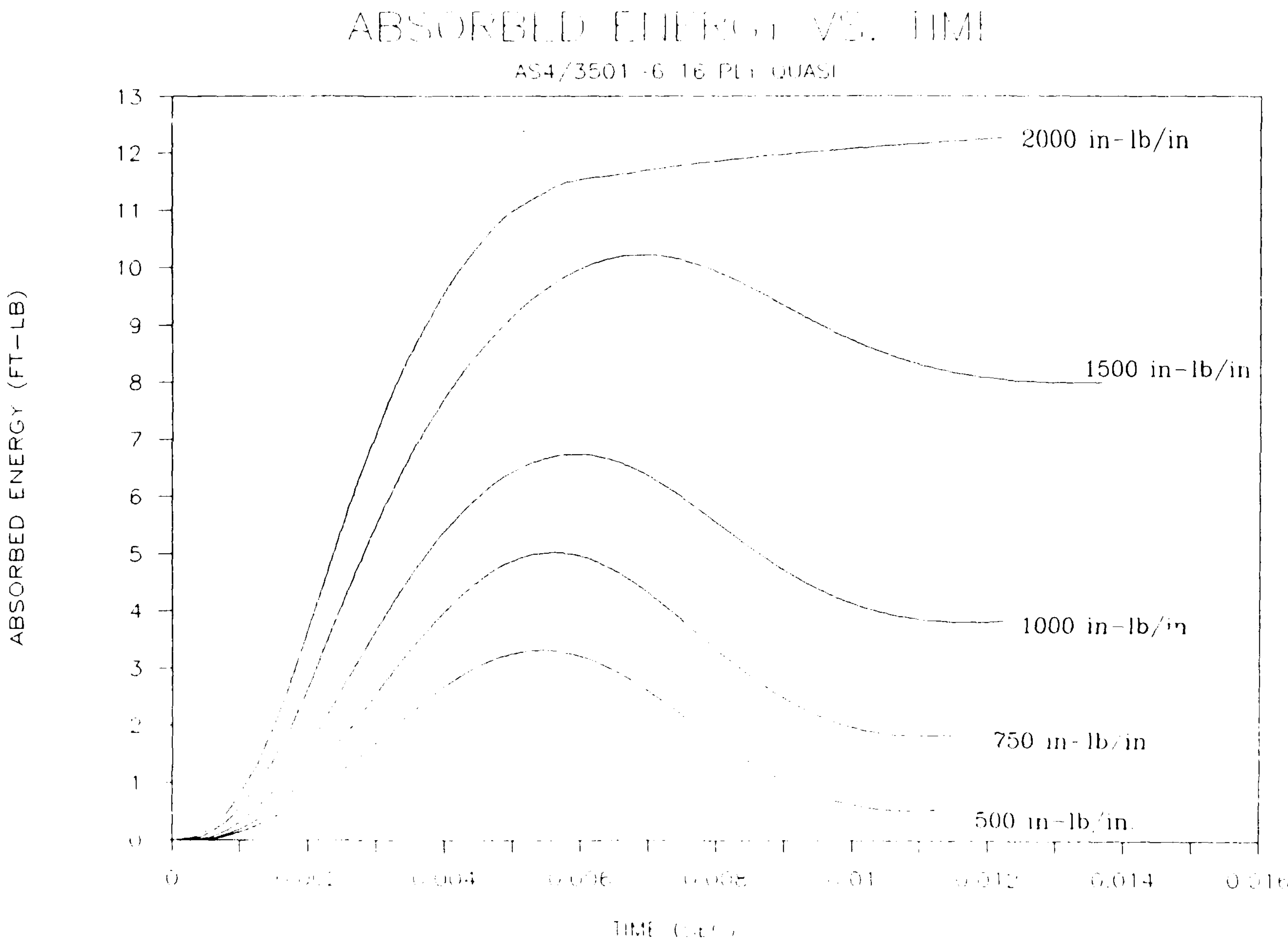

Figure 8 Calculated absorbed energy vs. time response of a 16 ply $[45/0/-45/90]_{2S}$ 4 x 6 in. AS4/3501-6 graphite/epoxy, specimens A-E, impacted with a 0.5 in. diameter tup, determined using equation 9.

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Appendix 1: Listing of the data acquisition computer routine, 1IMPACT, used to record the output of the force tup of the instrumented impact tower.

```
1 '      *******   THIS PROGRAM IS CALLED 1IMPACT.  ***********
10 ' THIS PROGRAM IS THE DATA AQUISITION PROGRAM FOR THE INSTRUMENTED DROP
20 ' TOWER.  THIS IS SET UP TO READ CHANNEL 0 AS THE FORCE TUP RESPONSE.
30 ' CHANNEL 1 IS USED AS THE TRIGGER FOR DATA ACQUISITION.  THIS PROGRAM
40 ' TAKES DATA AT A RATE OF 76 KHz AND WRITES IT TO A DATA ARRAY.
50 ' THE PROGRAM PLOTS THE FORCE VERSUS TIME. THE DATA IS AUTOMATICALLY
60 ' SCALED ACCORDING TO THE CALIBRATION OF THE INSTRUMENTED TUP.  YOU CAN
70 ' SAVE THE FILE IN ANY DIRECTORY WITH ANY NAME THAT YOU CHOSE.
80 ' IF THERE ARE ANY QUESTIONS, CONTACT R. CRANE, EXT 2165.
85 '
90 DIM DT%(2000),CH%(2000)  'DIMENSIONS ARRAY OF DATA POINTS
95 M = 2000        'THIS IS THE NUMBER OF DATA POINTS THE PROGRAM TAKES
100 CLS
110 KEYPRESSED = 0
130 '
140 '  LOAD DASH16.BIN DRIVER
150 '
160 DEF SEG = &H5000
170 BLOAD "C:\ILS\DAS\DASH16.BIN", 0
180 '
190 ' *** INITIALIZE WITH MODE 0
200 '
205 CLS
210 MD% = 0
220 DIO%(0) = &H330        ' SET I/O ADDRESS
230 DIO%(1) = 2            ' SET INTERRUPT LEVEL
240 DIO%(2) = 3            ' SET DMA LEVEL
250 FLAG% = 0
260 DASH16 = 0
270 CALL DASH16 (MD%, DIO%(0), FLAG%)
280 IF FLAG%<>0 THEN PRINT "INSTALLATION ERROR";STOP
290 '
300 ' ***  SET MULTIPLEXER SCAN LIMITS
310 MD% = 1
315 PRINT " ATTACH THE OUTPUT FROM THE 2310 STRAIN CONDITIONER TO CHANNEL 0"
316 PRINT " OF THE DATA ACQUISITION BOARD.  THIS WILL RECORD THE FORCE FROM"
317 PRINT " THE INSTRUMENTED TUP OF THE DROP TOWER."
318 PRINT
320 PRINT " ATTACH THE OUTPUT FROM THE TRIGGER TO CHANNEL 1 OF THE DATA"
321 PRINT " ACQUISITION BOARD.  THIS WILL BE USED TO ACTIVATE THE START "
322 PRINT " OF DATA COLLECTION"
323 PRINT
330 DIO%(0) = 0
350 DIO%(1) = 0
360 CALL DASH16 (MD%, DIO%(0), FLAG%)
370 IF FLAG%<>0 THEN PRINT "ERROR # ";FLAG%;"IN SETTING SCAN LIMITS":STOP
380 '
385 '  *** DO 1266 A/D CONVERSIONS AND PRINT AVERAGE
390 'THIS SECTION IS USED TO ZERO THE 2310 STRAIN CONDITIONER
391 PRINT
392 PRINT " THE FOLLOWING SECTIONS WILL ALLOW YOU TO ADJUST THE TRIM OF"
393 PRINT " THE 2310 SIGNAL CONDITIONER  ---  WHEN THE FOLLOWING READING"
394 PRINT " IS CLOSE TO 0, HIT ANY KEY TO CONTINUE"
400 WHILE NOT KEYPRESSED
405  MD% = 17
410 DIO%(0) = 10 ' DIVIDE 10 MHz BY 10 TO GIVE 1MHz FREQUENCY
415 DIO%(1) = 13 ' DIVIDE 1 MHz BY 12 TO GIVE 83.3 KHz FREQUENCY
420 FLAG% = 0
425 CALL DASH16 (MD%, DIO%(0), FLAG%)
430 DIO%(0) = 1266
```

```
435 DIO%(1) = &H6800   ' SEGMENT OF MEMORY TO RECIEVE DATA
440 DIO%(2) = 1   'INDICATES TYPE OF TRIGGER; 1 = TIMER, 0 = EXTERNAL TRIGGER
445 DIO%(3) = 0   ' 0 = ONE CYCLE,  1 = RECYCLE
450 MD% = 6
455 CALL DASH16 (MD%, DIO%(0), FLAG%)
460 MD% = 8
465 CALL DASH16 (MD%, DIO%(0), FLAG%)
470 IF DIO%(1) = 1 THEN GOTO 460
475 MD% = 9
476 DIO%(0) = 1266              ' NUMBER OF WORDS TO TRANSFER
477 DIO%(1) = &H6800            ' SEGMENT OF MEMORY TO TRANSFER FROM
478 DIO%(2) = 0                 ' SET TRANSFER TO BEGIN AT BEGINNING OF SEGMENT
479 DIO%(3) = VARPTR(DT%(0))    ' TO START TRANSFER AT BEGINNING OF ARRAY
480 DIO%(4) = VARPTR(CH%(0))    ' CHANNEL THAT DATA IS FROM
481 CALL DASH16 (MD%, DIO%(0), FLAG%)
482 SUM = 0
483 FOR I = 1 TO 1266
484 SUM = SUM +DT%(I)
485 NEXT I
486 ZERO= SUM/1266
487 LOCATE 15,20
488 PRINT USING "##.###";ZERO
489 KEYPRESSED$=""
490 KEYPRESSED$=INKEY$
491 IF KEYPRESSED$<>"" THEN KEYPRESSED=-1
492 WEND
495 ' *** SET PROGRAMMABLE TIMER RATE USING MODE 17
500 '     SO THAT TIMER CAN BE SET TO MAX. VALUE
510 ' NOTE THAT CURRENT TIME FOR 1 CHANNEL SCAN IS 1.30 E-5 SEC."
520 '
720 D=5
730 V = 26
740 TI#= 1E+07/130
750  MD% = 17
760 DIO%(0) = D  ' DIVIDE 5 MHz BY 10 TO GIVE 2MHz FREQUENCY
770 DIO%(1) = V  ' DIVIDE 2 MHz BY 26 TO GIVE 76.9 KHz FREQUENCY
780 FLAG% = 0
790 CALL DASH16 (MD%, DIO%(0), FLAG%)
791 PRINT
792 PRINT " INPUT THE WEIGHT OF THE IMPACTOR IN POUNDS ";
793 INPUT "",WGT
794 PRINT
795 PRINT " INPUT THE DROP HEIGHT FOR THE TEST IN INCHES ";
796 INPUT "",DHT
800 '
810 ' *** DO 2000 A/D CONVERSIONS AND TRANSFER TO MEMORY VIA DMA - MODE 6
820 '
850 PRINT
860 PRINT "THE SYSTEM WILL BEGIN TAKING DATA FROM ASSIGNED CHANNELS"
870 PRINT " AFTER THE TRIGGER ACTIVATES THE SYSTEM TO BEGIN"
871 PRINT
872 MD% = 19
873 DIO%(0) = 1
874 DIO%(1) = 500               ' set trigger level to 500 bits
875 DIO%(2) = 0                 ' set trigger level to positive slope
876 CALL DASH16 (MD%, DIO%(0), FLAG%)
880 DIO%(0) = M
890 DIO%(1) = &H6800   ' SEGMENT OF MEMORY TO RECIEVE DATA
900 DIO%(2) = 1   'INDICATES TYPE OF TRIGGER; 1 = TIMER, 0 = EXTERNAL TRIGGER
910 DIO%(3) = 0   ' 0 = ONE CYCLE,  1 = RECYCLE
```

```
920 MD% = 6
930 CALL DASH16 (MD%, DIO%(0), FLAG%)
940 MD% = 8
950 CALL DASH16 (MD%, DIO%(0), FLAG%)
960 IF DIO%(1) = 1 THEN GOTO 940
1060 '
1070 PRINT CHR$(7)
1080 '
1090 '*** TRANSFER DATA FROM MEMORY TO ARRAY USING MODE 9
1100 MD% = 9
1110 DIO%(0) = M                ' NUMBER OF WORDS TO TRANSFER
1120 DIO%(1) = &H6800           ' SEGMENT OF MEMORY TO TRANSFER FROM
1130 DIO%(2) = 0                ' SET TRANSFER TO BEGIN AT BEGINNING OF SEGMENT
1140 DIO%(3) = VARPTR(DT%(0))   ' TO START TRANSFER AT BEGINNING OF ARRAY
1150 DIO%(4) = VARPTR(CH%(0))   ' CHANNEL THAT DATA IS FROM
1160 CALL DASH16 (MD%, DIO%(0), FLAG%)
1170 PRINT CHR$(2)
1175 IF PP=1 GOTO 1750
1190 '
1200 ' READ DATA FROM MEMORY SEGMENT AND PRINT GRAPHICS
1220 '
1300 Q=0
1310 B=0
1320 S = (M-B)/640                 ' K SCALES TIME TO FIT ON X-AXIS
1330 FOR I = 0 TO M          ' SEARCH FOR MAXIMUM VALUE OF DISPLACEMENT
1340 IF ABS(DT%(I)) < Q THEN GOTO 1360    ' SO THAT GRAPHICS CAN BE SCALED
1350 Q = ABS(DT%(I))
1360 NEXT I
1370 PRINT "MAX VALUE OF DISPLACEMENT IS ";Q
1380 R=Q/100
1530 INPUT "DO YOU WANT TO PLOT THE DATA OF DISPLACEMENT VS. TIME";A$
1540 IF A$ = "N" OR A$ = "n" THEN GOTO 1750
1550 CLS:SCREEN 2:KEY OFF
1560 FOR I = 0 TO M-1
1570 PSET ((I)/S, 100-(DT%(I)/R))
1580 PSET ((I)/S, 100)
1590 NEXT I
1600 N = M
1740 INPUT "",A$
1750 PRINT "NUMBER OF DATA POINTS IS ";N
1755 PRINT
1756 PRINT "INSERT DATA DISK INTO DRIVE A  AND HIT RETURN";
1757 INPUT "",Z$
1760 PRINT "THE DATA WILL NOW BE SCALED, TO GIVE FORCE AND STORED TO A FILE"
1770 PRINT " TYPE THE FILE NAME THAT YOU WANT THE DATA STORED TO "
1775 PRINT " THE FILE NAME MUST HAVE A 'PRN' EXTENSION ";
1780 INPUT "",FILE$
1782 Q$ = ":"
1784 IF INSTR(FILE$,Q$)= 0  GOTO 1790
1786 B$=FILE$
1788 GOTO 1800
1790 C$ = "A:"
1792 B$ = C$+FILE$
1800 CLS:SCREEN 0
1810 '
1820 '*** TRANSFER DATA FROM ARRAY TO DESIGNATED FILE
1830 '
1835 PRINT
1840 PRINT " CURRENT ARRAY WILL BE TRANSFERRED TO A FILE, ";B$
1870 PRINT " THE DATA WILL BE TRANSFERRED AS CONVERTED DATA TO THIS FILE"
```

```
1880 PRINT "THE CONVERSION USED IS SLOPE = 1127.63 LB/VOLT"
1890 PRINT " WITH AN INTERCEPT OF 0.0 LB/VOLT"
2090 PRINT "THE NUMBER OF DATA POINTS ARE ";M-B
2095 PRINT
2100 OPEN B$ FOR OUTPUT AS #1
2110 PRINT "THE FREQUENCY OF DATA ACQUSITION IS ";TI#
2112 T = 1/TI#
2115 PRINT
2116 PRINT "THE TIME INTERVAL BETWEEN DATA POINTS IS ";T
2118 Q$= "DROP HEIGHT IS "
2119 PRINT #1,Q$
2120 PRINT #1,DHT
2121 R$= "WEIGHT OF IMPACTOR IS "
2122 PRINT #1,R$
2123 PRINT #1,WGT
2124 R$="TIME INTERVAL BETWEEN DATA POINTS IS "
2125 PRINT #1,R$
2126 T=1/TI#
2127 PRINT #1,T
2128 FOR I = B TO M-1
2130 DT=(DT%(I)/409.6)*(-1127.63)
2140 PRINT #1, DT
2160 NEXT I
2170 CLOSE #1
2175 PRINT
2180 PRINT "WOULD YOU LIKE TO RUN ANOTHER TEST ";
2190 INPUT "",Z$
2200 IF Z$ = "Y" OR Z$ = "y" THEN GOTO 95
2210 END
```

Appendix 2: Listing of the analysis routine computer program, 2DROPTOW, used to calculate absorbed energy, displacement, velocity from the force recorded from the instrumented impact tower.

```
1 '   **********  THIS PROGRAM IS CALLED 2DROPTOW.   ********
2 '
10 ' THE FOLLOWING PROGRAM IS USED TO CONVERT DATA FROM THE DROP
20 ' TOWER, STORED IN FORCE AND TIME, TO ENERGY VS. TIME,
30 ' DISPLACEMENT VS. TIME, VELOCITY VS. TIME, ACCELERATION VS. TIME
40 ' FORCE VS. TIME. THE PROGRAM WILL PROMPT YOU FOR
50 ' ALL APPROPRIATE INFORMATION.
60 '
65 DEFDBL A-H,O-Z
68 DEFINT I-N
69 DIM F(2000) 'DIMENSIONS ARRAY FOR FORCE VALUES TO 2000
70 PRINT " INPUT THE NAME OF THE DATA FILE THAT YOU WANT TO USE"
80 PRINT " FOR YOUR DROP TOWER ANALYSIS. INCLUDE THE APPROPRIATE"
90 PRINT " DIRECTORY ";
100 INPUT "",FILE$
105 OPEN FILE$ FOR INPUT AS #1
112 INPUT #1,A$   'READS ASCII INFORMATION FROM FILE
113 INPUT #1,DH   'READS DROP HEIGHT FROM FILE
114 INPUT #1,A$   'READS ASCII INFORMATION FROM FILE
115 INPUT #1,IW#  'READS IMPACTOR WEIGHT FROM FILE
116 INPUT #1,A$   'READS ASCII INFORMATION FROM FILE
117 INPUT #1,DELTAT 'READS TIME INTERVAL BETWEEN DATA POINTS FROM FILE
170 PRINT
180 PRINT "DATA WILL BE TAKEN FROM FILE ";FILE$
185 PRINT
190 PRINT " DROP HEIGHT IS ";DH;" INCHES,  IMPACTOR WEIGHT IS ";IW#;"POUNDS"
240 PRINT
250 ' THE DATA FROM THE DROP TOWER TEST IS NOW READ INTO ARRAYS
280 VINIT = SQR(64.4#*DH/12#)  'CALCULATES INITIAL VELOCITY FROM POTENTIAL
290 PRINT                      ' ENERGY, ASSUMING NO LOSSES
300 PRINT " THE INITIAL IMPACT VELOCITY IS ";VINIT;"FT/SEC"
310 FMAX = 0
320 TMAX = 0
328 NPT = 0
330 WHILE NOT EOF(1)
335 NPT = NPT+1
340 INPUT #1,F(NPT)    'READS IN FORCE VALUES
350 IF F(I) < FMAX THEN GOTO 380
360 FMAX = F(I)
380 WEND
381 CLOSE #1
382 PRINT "INPUT THE FILE NAME PLUS DIRECTORY YOU WISH TO STORE THE"
383 PRINT " CONVERTED DATA TO ";
384 INPUT "",B$
385 PRINT
386 PRINT "YOUR CONVERTED INFORMATION WILL BE STORED TO FILE ";B$
387 OPEN B$ FOR OUTPUT AS #2
388 PRINT #2,"FORCE, TIME, ENERGY, VELOCITY, DISPLACEMENT, ACCELERATION"
390 PRINT
400 PRINT
410 PRINT" THE PROGRAM WILL NOW DETERMINE ENERGY, VELOCITY, DISPLACEMENT, TIME"
420 EO = 0                    'ABSORBED ENERGY
430 V = VINIT                 ' INITIAL VELOCITY
432 ACCEL=32.2#               ' ACCELERATION DUE TO GRAVITY
435 D = 0                     ' D = DISPLACEMENT OF PANEL
440 FOR I = 1 TO NPT          ' NPT = NUMBER OF DATA POINTS
450 VM = V                    ' VM = PREVIOUS VELOCITY
455 ACEL1=ACCEL               ' ACEL1 = PREVIOUS ACCELERATION
460 ACCEL = (1#-F(I)/IW#)*32.2#  ' ACCELERATION IN FT/SEC^2
470 V = V + (ACCEL+ACEL1)*DELTAT/2#  ' T = TIME INTERVAL, V IN FT/SEC
```

```
480 DDELTA = (V + VM)*DELTAT*12#/2#  ' (V+VM)/2 = AVE VEL., DDELTA IN INCHES
490 D = D + DDELTA
500 EO = EO + (VM^2-V^2)*IW#/64.4#- IW#*DDELTA/12# ' EO IN FT-LBS
505 T=DELTAT*(I-1)
510 PRINT #2,CSNG(F(I)),CSNG(T),CSNG(EO),CSNG(V),CSNG(D),CSNG(ACCEL)
520 NEXT I
523 CLOSE #1
524 CLOSE #2
525 PRINT
530 INPUT " WOULD YOU LIKE TO CONVERT ANOTHER FILE ";A$
540 IF A$ = "Y" OR A$ = "y" THEN GOTO 70
550 END
```

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